Report No. RD-66-11

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Project No. 430-209-01V

EVALUATION OF MINIMUM APPROACH LIGHT SYSTEM FOR LOWER ACTIVITY AIRPORTS

FEBRUARY 1966

FEDERAL AVIATION AGENCY
Test and Evaluation Division
National Aviation Facilities Experimental Center
Atlantic City, New Jersey

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EVALUATION OF MINIMUM APPROACH LIGHT SYSTEM FOR LOWER ACTIVITY AIRPORTS

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Prepared by:

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Federal Aviation Agency, National Aviation Facilities Experimental Center, Test and Evaluation Division, Atlantic City, New Jersey. EVALUATION OF MINIMUM APPROACH LIGHT SYSTEM FOR LOWER ACTIVITY AIRPORTS by T. H. Paprocki and R. F. Gates, Interim Report, February 1966, 41 pp., incl. 13 illus., plus 1 app. (Project No. 430-209-01V, Report No. RD-66-11).

ABSTRACT

Flight tests were conducted during actual Category I weather conditions at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, to determine the suitability of three approach light patterns in providing guidance for aircraft approach speeds of 125 knots using ILS into lower activity airports. Each pattern tested provided less visual guidance (fewer lights) than the U. S. Standard Approach Light System. A fourth pattern which was not available during the weather period will be evaluated and test results reported at a later date.

It was concluded that the minimum pattern provided adequate visual guidance in a Category I visiblity condition with a high approach success rate provided a minimum decision height of 150 feet is authorized with reported ceilings of 200 feet and higher.

Several amendments to operating practices were suggested to permit flight to a minimum decision height below a reported ceiling height.

It was also concluded that runway visual range alone provided a poor indication of what approach light contact height to expect and, consequently, there was a requirement to provide slant visibility measurements to improve the approach success rate.

INTRODUCTION

A. PURPOSE: The purpose of this project was to determine the minimum Approach Light System (ALS) that would provide adequate visual guidance to a pilot under Category I weather conditions with an aircraft approach speed of 125 knots.

B. BACKGROUND: The U. S. Standard ALS is a high intensity, highly developed pattern extending outward for a distance of 3,000 feet from the runway threshold. It is installed at approximately 200 airports in the United States and has been adopted by several foreign countries as a standard system. International Civil Aviation Organization Standards, Annex 14, include the U. S. system as one of two approach light patterns serving precision approach runways for Category I operations. A Category I operation is defined as an operation down to a decision height of 200 feet above the runway and a Runway Visual Range (RVR) of the order of 2,600 feet.

Because the cost of the U. S. Standard ALS is approximately $170,000 installed and flight checked, a requirement exists to reduce the cost, thereby permitting more systems to be installed, particularly at airports served by local service airlines.

Four approach light patterns were selected for evaluation. All of these patterns were formed by eliminating components of the U. S. Standard ALS. A previous evaluation of approach lighting aids at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey,(1) indicated that a short thinned-out ALS in combination with two rotating incandescent approach light beacons might prove to be a solution to the development of an effective, economical ALS for a Category I operation. This pattern was adopted as one of the four patterns to be evaluated.

Nantucket Memorial Airport, Nantucket, Massachusetts, was selected as the test site based on the high frequency of fog occurrence during summer months for the past five years. It was anticipated that the project could be completed at Nantucket within a few weeks' time during July and August 1965. The weather, however, at Nantucket was unseasonal to such an extent that only one flight consisting of seven approaches was conducted in reduced

(1)Thomas H. Paprocki, "Evaluation of Simplified Approach Lighting Aids," Federal Aviation Agency Final Report, Project 421-010-00V November 1963.

visibilities. During the summer the ALS at NAFEC was modified so that the test patterns for this project could be evaluated at NAFEC in addition to Nantucket. The pair of incandescent approach light beacons were not moved from Nantucket to NAFEC until November 1965. In the meantime, sufficient weather data had been obtained on the patterns available at NAFEC to permit this report to be issued on the operational use of three patterns. A separate report for the fourth pattern (Pattern II) will be issued after additional weather experience is obtained.

C. EQUIPMENT DESCRIPTION:

1. General: Each of the four patterns (Figure 1) evaluated was a variation of the U. S. Standard ALS. Individual patterns were obtained by "thinning out" or "shortening" the standard patterns or by using a combination of both modifications. In the following description of individual pattern details the aforementioned terms will have these meanings:

   a. Thinned out: Distance between centerline-light-barrettes is 200 feet instead of the standard 100-foot interval. This was obtained within the standard system by turning off alternate centerline barrettes.

   b. Shortened: Total length of the system is less than the standard 3,000 feet. This was obtained within the standard system by turning off all centerline-light-barrettes beyond the desired distance from threshold.

2. Detailed Pattern Information:

   a. Pattern I: This was a thinned out and shortened system, having a total length of 1,400 feet and an interval of 200 feet between centerline-light-barrettes. In addition, the 1,000-foot (100 feet wide) decision bar of the standard system was reduced 30 feet in width by turning off the outer three lamps on each side. The red terminating bar at 200 feet was retained, but the red-wing-bars at 100 feet (pre-threshold) were deleted. Standard condenser-discharge lights were used at all white-light-centerline-barrettes from 400 feet to 1,400 feet from threshold. On the lower three intensity steps, these lights operate only from the 1,000-foot barrette outward. This was the most economical of the four patterns evaluated.

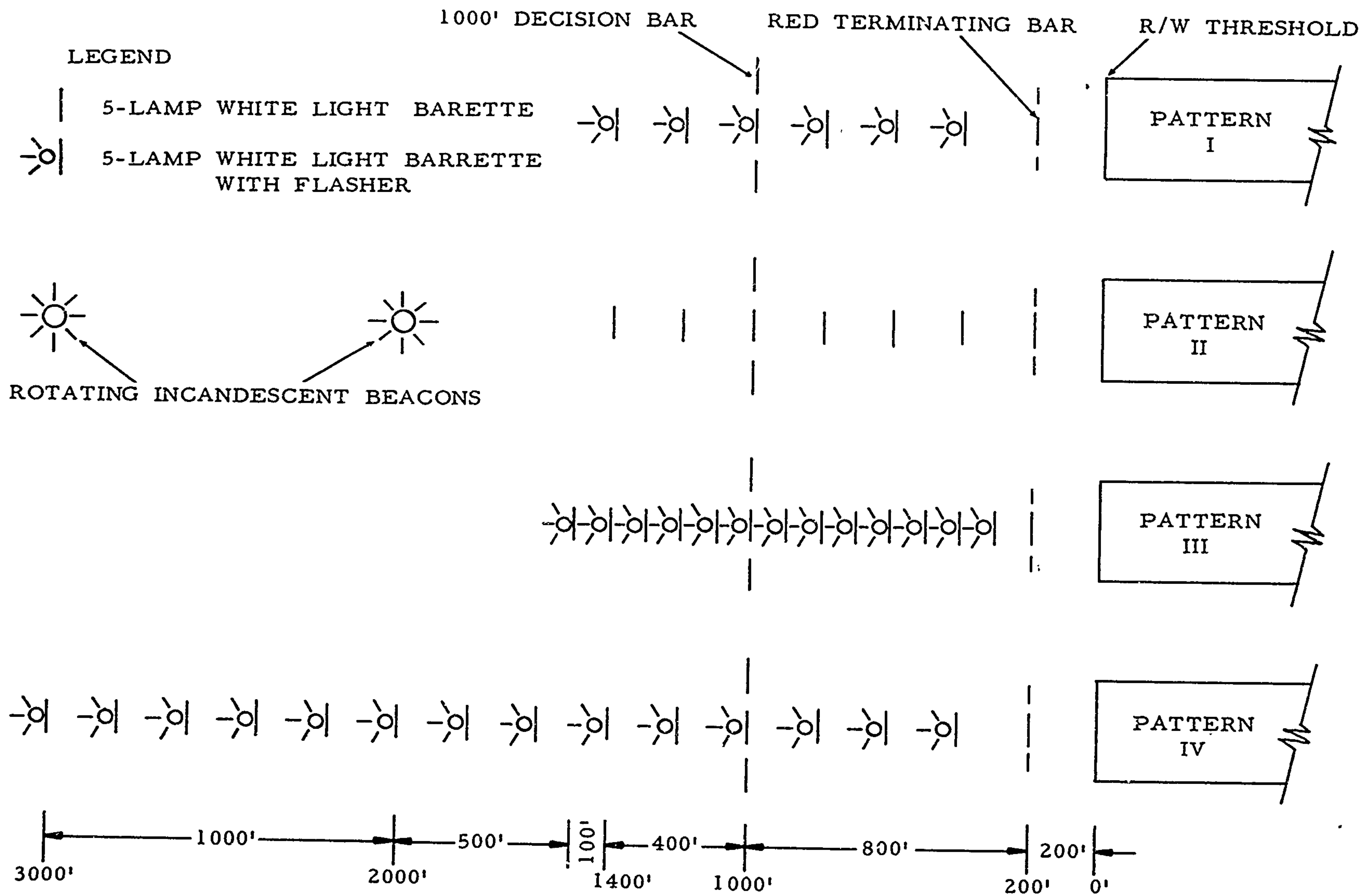


FIG. 1 THE FOUR SIMPLIFIED APPROACH LIGHT PATTERNS EVALUATED

b. Pattern II: This was the same system as Pattern I with the exception that two high-intensity rotating incandescent beacons, flashing at a rate of 72 flashes per minute, were added at distances of 2,000 feet and 3,000 feet from threshold respectively. No condenser-discharge lights were utilized. This was the second most economical of the four patterns. As previously stated, test data on this pattern has not been obtained at this writing.

c. Pattern III: This was a shortened system having a total length of 1,500 feet and the standard 100-foot interval between centerline-light-barrettes. The 1,000-foot decision bars were also reduced in width, as described in Pattern I, and the red-wing-bars at 100 feet were deleted. Standard condenser-discharge lights were used at all white-light-centerline-barrettes from 300 feet to 1,500 feet from threshold. On the lower three intensity steps these lights operated only from the 1,000-foot barrette outward. This was the third most economical of the four patterns.

d. Pattern IV: This was a thinned-out system having a total length of 3,000 feet as in the standard system and an interval of 200 feet between centerline-light-barrettes. The 1,000-foot decision bar was left at the standard width, but the 100-foot red-wing-bars were again deleted, as in the other systems. Standard condenser-discharge lights were used at all white-light-centerline-barrettes from 400 feet to 3,000 feet from threshold. On the lower three intensity steps, these lights operated only from the 1,000-foot barrette outward. This was the least economical of the four patterns.

e. Pattern A: This was the U. S. Standard ALS consisting of 28 five-lamp white-light-centerline-barrettes located at 100-foot intervals along the runway centerline extended. Total system length was 3,000 feet. The station located 1,000 feet from the runway threshold has a width of 100 feet. An 11-lamp red-light-centerline-barrette was located at a distance of 200 feet from the runway threshold to serve as a pre-threshold indication. Two five-lamp red-light-barrettes were located on each side of the runway centerline extended at a distance of 100 feet from the runway threshold to provide further pre-threshold warning. Standard condenser-discharge lights were located on each of the white-

-centerline-barrettes. These units flash from the 3,000-foot barrette to the 1,000-foot barrette with ALS intensity Steps 1, 2, and 3; and to the 300-foot barrette with intensity Steps 4 and 5.

3. Detailed Characteristics and Cost Factors: All electrical and structural components of the thinned-out and shortened experimental systems were identical to those used in the U. S. Standard ALS. The rotating incandescent approach light beacons of Pattern II were mounted on the ALS tower structure and consisted of six lamps equally spaced circumferentially on a rotating circular base plate (see Figure 2). As the rotational speed of the beacons was 12 r/min, each appeared as a white light source flashing at a rate of 72 flashes per minute. No provision for synchronization of the two beacons was made. There were 499-watt, 20-amp/PAR56Q/3 lamps installed to provide an effective intensity of 98,000 candlepower for daylight approaches.

The reduced cost or "economy" of each system was derived: (1) From the reduction in total number of components utilized; (2) from the reduced power supply and regulator capacity required; and (3) from the reduction and/or shortening of cable runs (to include trenching) required. In addition, two of the patterns (Patterns I and III) require 50 percent less airport-owned property within the runway approach zone and may be installed at locations where terrain considerations preclude the installation of a full-length (3,000 feet) ALS. Pattern II requires only two small areas of property beyond the 1,500-foot point whereas for Pattern IV, land costs would be the same as for the U. S. Standard system.

4. Runway Threshold Lights: The runway threshold used in the test program was the U. S. Standard threshold for precision approach runways consisting of green lights spaced five feet apart across the end of the runway between points 35 feet outside the runway edges. Switching was not available to reduce the number of lights in the threshold.

Considerable experience has been gained on runway thresholds having a gap equal to one-half the runway width with green lights symetrically disposed about the gap. Such a threshold has been established as a minimum pattern for Category I precision approach runways in ICAO Annex 14.

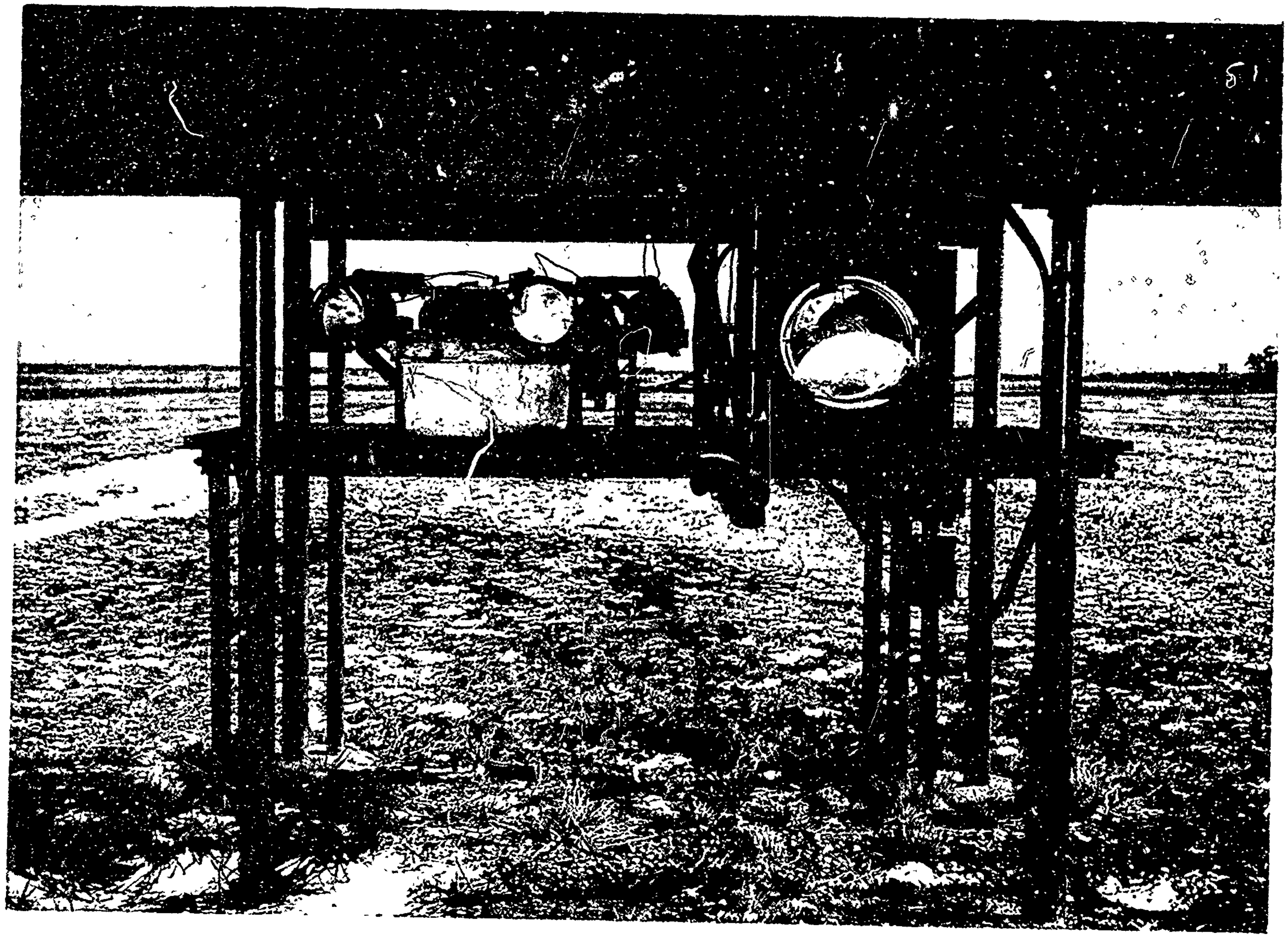


FIG. 2 APPROACH LIGHT BEACON MOUNTED ON ALS STRUCTURE

It was decided that in the interest of expediting the project, threshold lighting would not be evaluated and the minimum configuration established in ICAO Annex 14 for a Category I precision approach runway would be assumed to provide adequate threshold lighting.

DISCUSSION

A. TEST PROCEDURES: Pilots were briefed concerning the objectives of the program and the procedures to be used for the test. The briefing stressed that the objective was to determine the minimum system which would provide adequate visual guidance rather than the best system. All flights were conducted in actual weather.

The subject pilot flew the approach from the left seat with the safety pilot handling power to maintain 125 knots airspeed and to look for lights. The safety pilot called "lights" when first sighted which was the signal for the subject pilot to look for lights. When the subject pilot called "lights," the safety pilot read his altimeter for Approach Light Contact Height (ALCH), and the observer read the localizer and glide path indications. These data were logged in addition to information concerning angle of bank during the maneuver to the runway, whether the aircraft passed over or outside the runway threshold, and whether the touchdown was made in the first one-third of the runway. After the approach was conducted, the pilot was asked to rate approach light guidance as adequate or inadequate and to provide general comments on intensity, condenser-discharge lights, etc.

The test plan called for at least one-half of the approaches to be conducted with a displacement of 300 feet left or right at the middle marker. It was determined during preliminary flights that pilots encountered considerable difficulty in flying a displaced needle indication; consequently, a localizer bias device (see Figures 3 and 4) was developed that enabled selection of any displaced localizer indication desired. The pilot flew the displaced localizer course by flying a centered needle indication. This bias device proved to be most useful since on two occasions aircraft which were not modified to accept the bias device were used and weather data for a few runs were discarded due to the inability of the pilot to fly a displaced localizer needle indication.

The following definition of a successful approach was agreed upon for the project:

1. Approach light guidance is obtained at or above a 200-foot height, using a calibrated altimeter system.

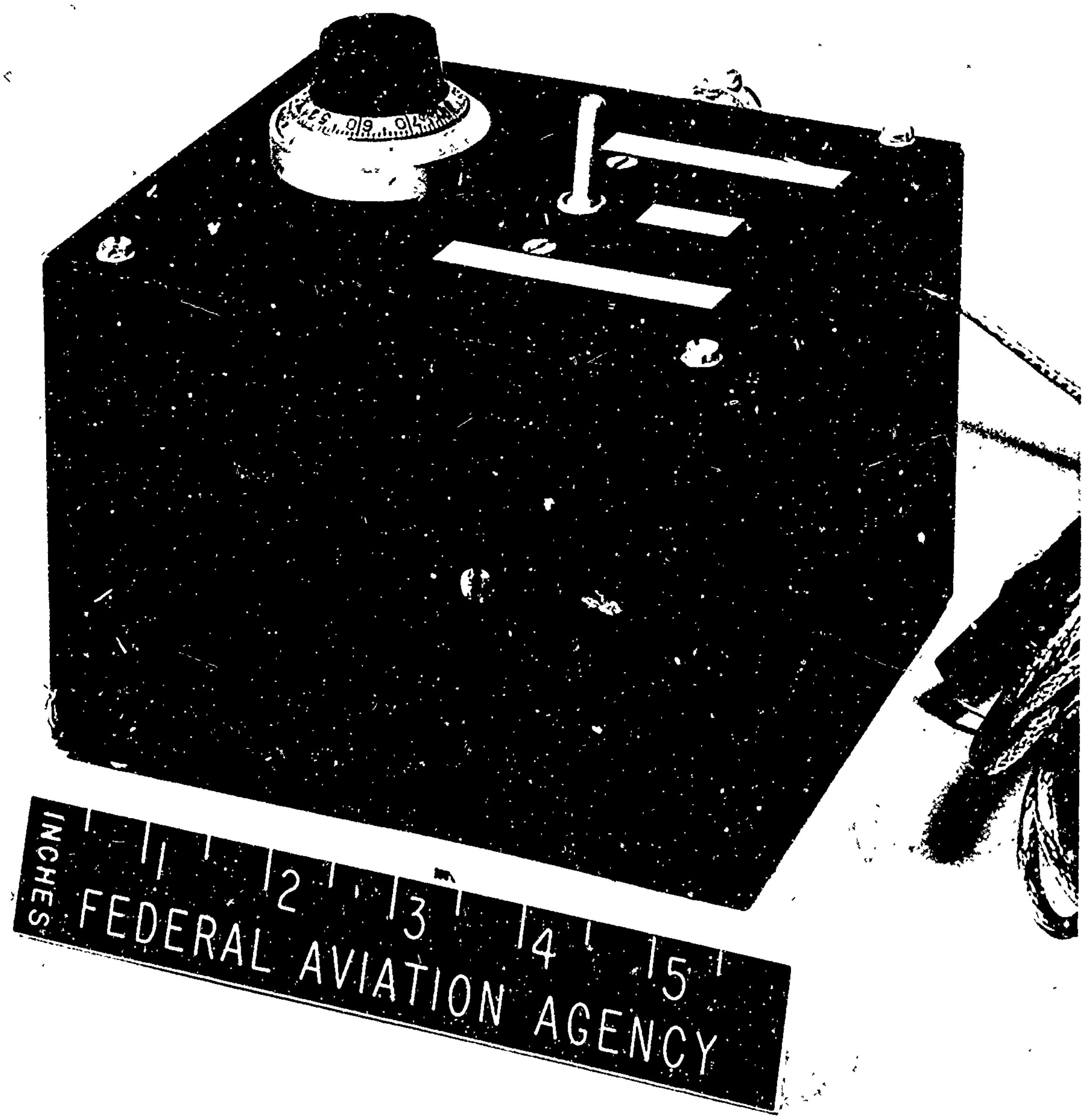
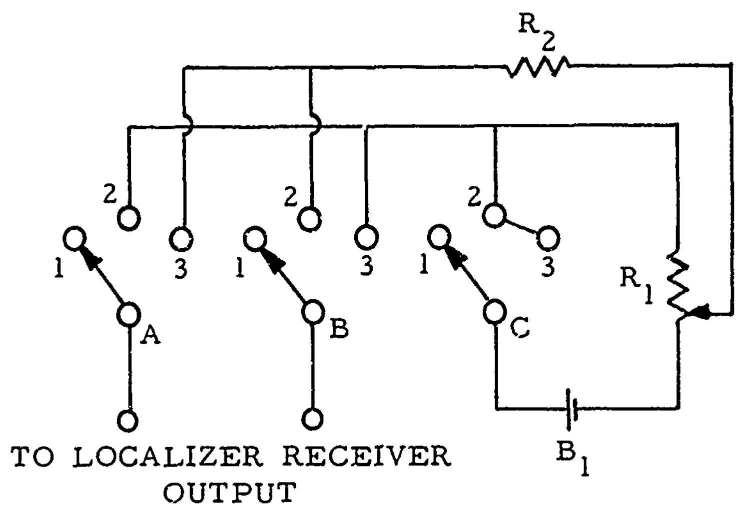


FIG. 3 LOCALIZER BIAS DEVICE



R_1 - 300K OHMS 10 TURN POTENTIOMETER

R_2 - 22K OHMS

B_1 - 13 1/2 VDC BATTERY

SWITCH POSITION: 1 OFF
2 LEFT COURSE
3 RIGHT COURSE

(AMOUNT OF BIAS VARIABLE FROM 0 TO 150 mV DEPENDING UPON ADJUSTMENT OF POTENTIOMETER R_1)

FIG. 4 CIRCUIT FOR LOCALIZER BIAS DEVICE

2. The aircraft crosses the runway threshold at a point between the runway edge lights and is tracking so as to touchdown within the first one-third of the runway.

3. The visual guidance received enabled the pilot to determine that he could maneuver the aircraft to a successful landing (or landing position).

To obtain runway visibility (called visual range for report purposes) at the time of each approach by project aircraft, a human observer was stationed in a small tower located at a distance of 1,000 feet from the runway threshold within the approach zone. The tower provided an eye-level height of nine feet above the runway threshold elevation and was offset to the right of the runway centerline extended so that the observer might view the high-intensity runway edge lights along the opposite side of the runway. The observer maintained a constant count of the number of runway edge lights visible from his position and thus was able to relay, via VHF radio, the existing visual range to the project aircraft during each approach. The observer also noted on his data sheet the visual range and background brightness existing at the time the aircraft passed overhead on final approach.

An effort was made to obtain subject pilots for the program from industry. Problems of weather forecasting were such that it was not possible to coordinate the availability of industry pilots in the short time available before weather flights were dispatched. Consequently, all subject pilots were from NAFEC. Since the report of ALCH became the most important data for the project, a limited cross section of subject pilot personnel was of less significance than in most visual aid evaluations where pilot opinion is often the primary data for a test program. Initially, a sequential analysis test program was planned to permit successive evaluation of each of the four experimental ALS patterns. Starting with the lowest cost or most economical pattern, each pattern was to be tested, in turn, to failure or acceptance. In this manner, the most economical but still adequate pattern could be determined with the minimum of evaluation time and effort. The test program was to be terminated as soon as a pattern was found to provide satisfactory guidance for the weather conditions specified. The weather specified was that the runway visibility, as determined by a human observer, would be between 2,400 and 3,200 feet. When ceilings were measured, they would be no less than 200 feet.

Early in the actual flight testing phase of the evaluation, however, it was determined that a number of unanticipated situations were developing. Among the more important of these were the following:

1. Indefinite (obscuration) ceiling reports, initially not a stressed portion of the criteria, were having a much greater influence upon pattern performance than had been anticipated. Moreover, this influence of indefinite ceiling variation was of much greater significance than that of runway visibility variation, the most important of the initially determined criteria.

2. Visibility conditions greater than 3,200 feet were reported when low ALCH reports were obtained and visibility was varying greatly from series to series (i.e., on different dates). Therefore, evaluation of single patterns, as is necessary in a "test to accept or reject" type operation, often offered unfair advantage to one pattern or the other. In order to evaluate the four patterns under even approximately equivalent weather conditions, it became necessary to change patterns on successive approach runs in the belief that weather conditions would be more comparable for all patterns tested in that series.

3. During the evaluation, control testing of Pattern A resulted in an indication of only marginal acceptability for this more complex pattern under ceiling and visibility conditions specified for the test. This suggested the possibility that other factors, such as weather reporting procedures, rules of flight operations, and aircraft equipment capabilities might have to be considered concurrently.

Considering these developing situations, it was determined that in order to obtain the greatest benefit from the program, a change in approach or viewpoint would be necessary. Instead of attempting to determine which pattern would provide the minimum adequate guidance for the given conditions, the more reasonable course of action was to determine, "For what conditions of ceiling and visibility does each pattern under evaluation provide adequate approach guidance?" Having decided on this change to the method of approach, the evaluation was continued to test, insofar as possible, the patterns in an alternating sequence whenever suitable Category I weather conditions occurred at NAFEC and Nantucket. To accomplish this, it was necessary to drop the "test to failure or acceptance" concept and obtain all possible data on each of the four patterns under various conditions of ceiling and visibility. This change in the test procedure was made about midway in the test program.

B. TEST RESULTS:

1. General: A total of 79 approaches was conducted in actual weather conditions. Once a mission was launched, uninterrupted approaches were conducted until the weather improved, subject pilots became fatigued, or fuel reserve was at the allowable minimum.

   Of the 79 approaches, 21 were outside the following criteria which were used in determining whether a run should be discarded, due to weather conditions, in determining approach success rates:

   a. The visual range as determined by the human observer at the time of the approach was below 2,400 feet and: (1) A missed approach occurred; (2) a low ALCH resulted; or (3) the pilot judged the ALS to be inadequate. No runs were discarded because of too great a visual range if measured ALCH was at or below 200 feet.

   b. A measured ceiling of 100 feet was reported and: (1) A missed approach occurred; or (2) the pilot judged the ALS to be inadequate. No runs were discarded because the ceiling height was reported as indefinite.

   c. A ceiling of 300 feet and above was reported and the pilot ALCH was above 200 feet.

   Five runs were eliminated where pilots exceeded 0.6 of full-scale needle deviation (90 microamperes) on the localizer course and a missed approach occurred. Data were used where pilots exceeded 0.6 of full-scale needle deviation if the approach was successful and the pilot judged the ALS to be adequate. One run was eliminated because a subject pilot, on his first approach, misunderstood the flight procedures and conducted a missed approach prior to visual contact being made with the ALS.

   Applying the aforementioned criteria, 52 runs were used for data analysis purposes.

2. Adequate Versus Inadequate Guidance Ratings: Pilots rated guidance as adequate for 47 of the runs and inadequate for five of the runs. (The rating of adequate meant that after making contact with the approach lights, the visual guidance derived

from the system enabled the pilot to complete his approach without undue strain or excessive maneuvering.) Table I shows the pertinent data for the five runs rated as providing inadequate guidance. All approaches in Table I, however, resulted in landings except for run No. 32. This was the only missed approach among the 52 approaches selected for data analysis purposes.

3. Approach Light Contact Height: The primary data on system performance was derived from pilot reports of ALCH and calculation of ALCH using motion picture film. Pilot reports of ALCH (along with ILS deviation) for the 52 runs available for data analysis purposes are shown in Figures 5 through 12.

The distance from the runway threshold for each run was compared to that obtained from motion picture film analysis using a photo-optical data analyzer. Only those runs are included for which motion picture film was available; and in a few instances, data for runs discarded for procedural reasons were used in this analysis. The average distance from the runway threshold for the two methods is shown in Table II.

The shorter distances shown for Pattern III in Table II, when compared to those for Pattern I, were due to the higher percentage of approaches on Pattern III being executed in more adverse weather conditions. Only one approach for Pattern I was made in a reported ceiling of 100 feet (W1X) or lower as opposed to five for Pattern III. It is reasonable to assume that Pattern III should have provided as high or higher ALCH averages than Pattern I in the same weather environment. To make a check on this assumption, it was possible to compare Pattern I and Pattern III when they were flown alternately in the same weather period. The average ALCH for six approaches on each pattern, as shown in Table III, was 167 feet for Pattern I and 169 feet for Pattern III.

Since similar test results were obtained with Patterns I and III, a comparison of a combination of these patterns with the Pattern A in the same weather period provides further information as to the relative effectiveness of short systems versus the standard length lighting system. The results of this comparison are given in Table IV.

TABLE I.

DATA FOR APPROACHES PILOTS RATED VISUAL GUIDANCE AS INADEQUATE

Run No.	Pattern	Localizer Displacement (Microamperes)	ALCH	Weather	Pilot Comment
32 (night)	I	60L	173 Ft.	W3X* 4000 Ft. RVR	Could have landed but required violent maneuver. Did not have enough guidance when co-pilot called "lights."
43 (day)	III	90R	133 Ft.	WIX 3000 Ft. RVR	Over-corrected and was still maneuvering over runway. Did not see enough lights.
68 (night)	I	0	186 Ft.	W0X 2600 Ft. RVR	ALS only fair.
69 (night)	III	0	166 Ft.	W0X 2600 Ft. RVR	Could not tell any difference in Pattern before (68).
70 (night)	IV	30R	196 Ft.	W0X 2800 Ft. RVR	None noted.

* (W) means ceiling height is indefinite; (3) means ceiling height is approximately 300 feet; (X) means that 100 percent of the sky is hidden by precipitation or obscuration to vision (base at surface).

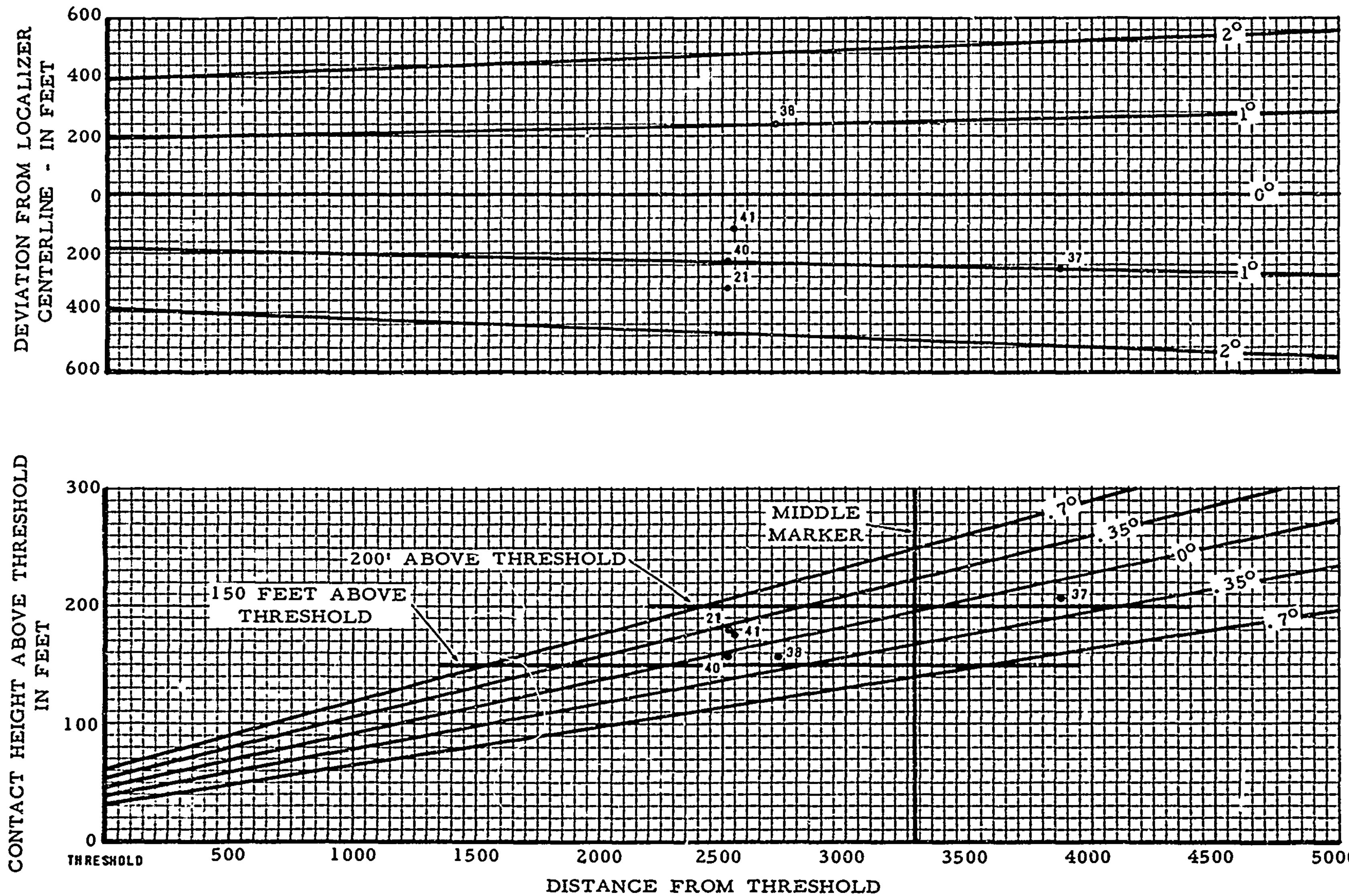


FIG. 5 ALCH AND ILS DEVIATION - PATTERN I, DAY APPROACHES

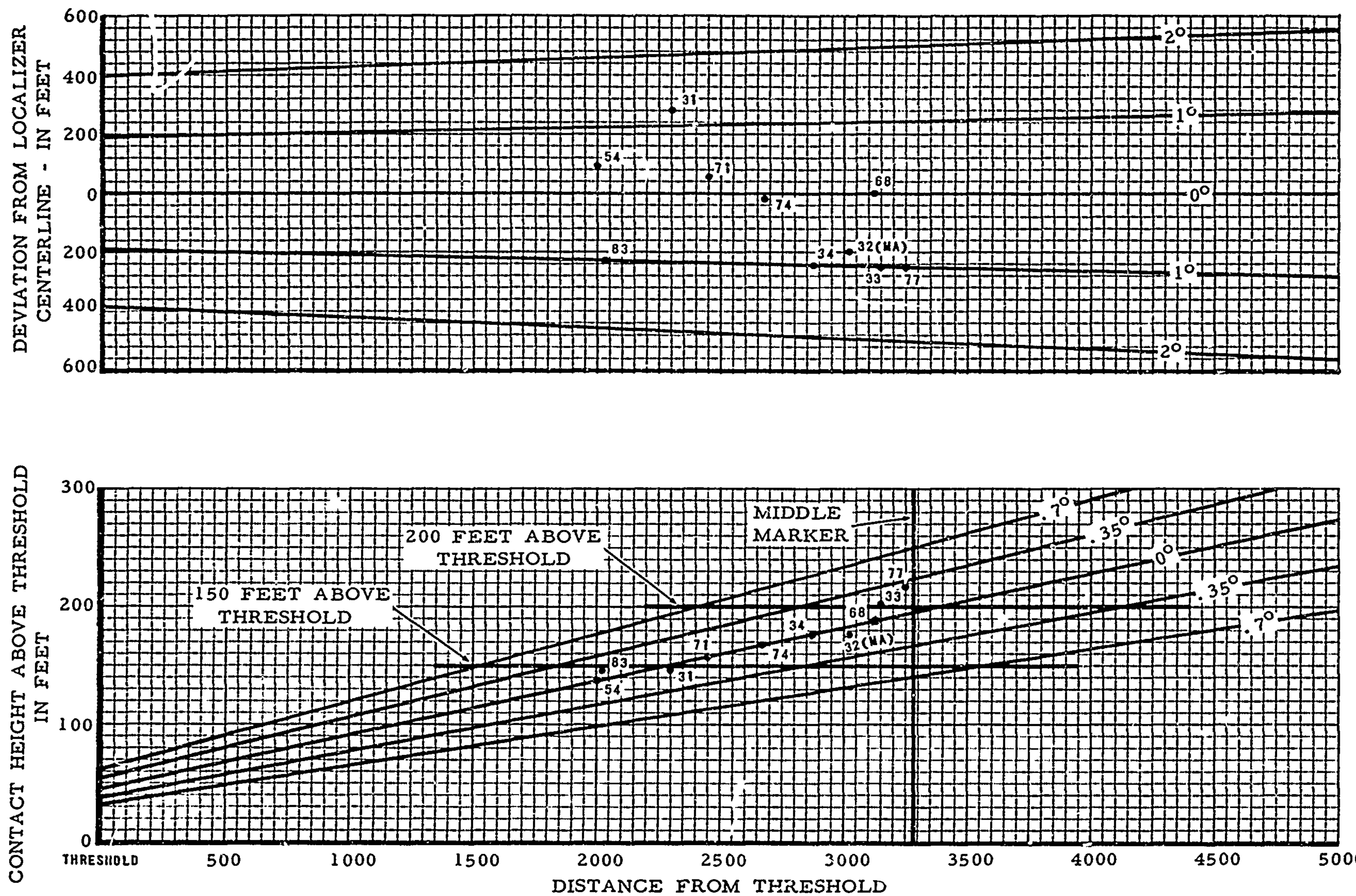


FIG. 6 ALCH AND ILS DEVIATION - PATTERN I, NIGHT APPROACHES

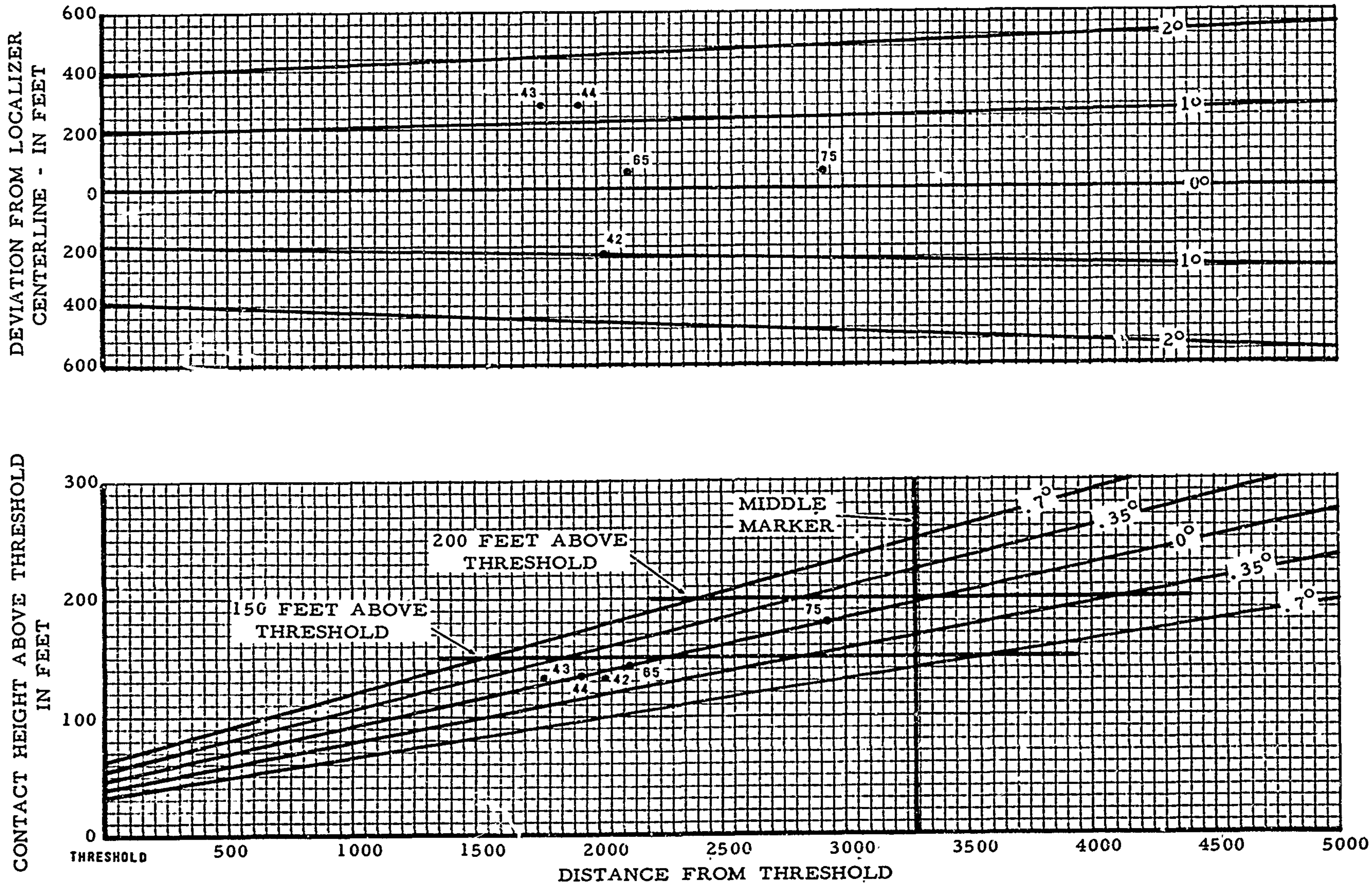


FIG. 7 ALCH AND ILS DEVIATION - PATTERN III, DAY APPROACHES

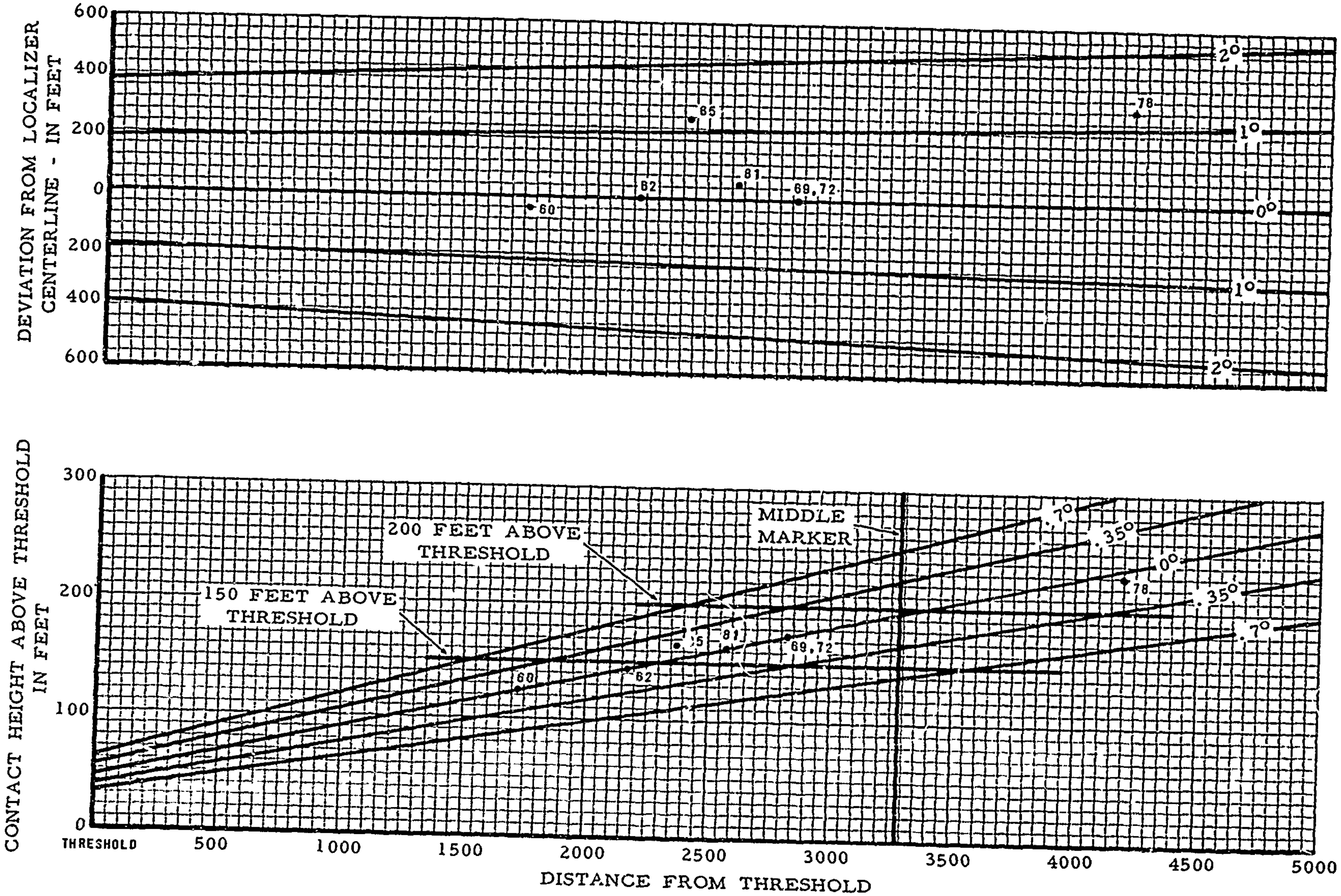


FIG. 8 ALCH AND ILS DEVIATION - PATTERN III, NIGHT APPROACHES

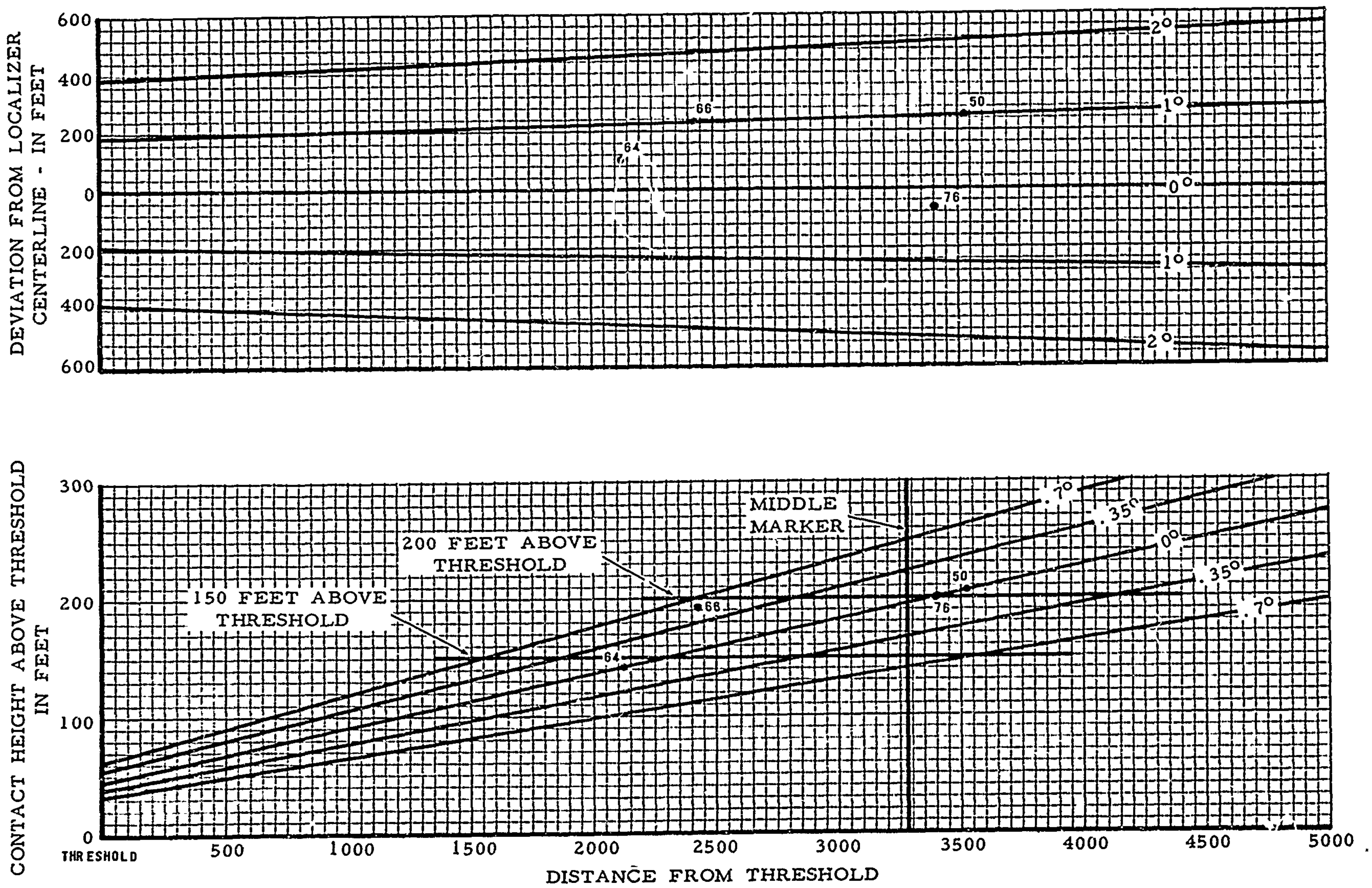


FIG. 9 ALCH AND ILS DEVIATION - PATTERN IV, DAY APPROACHES

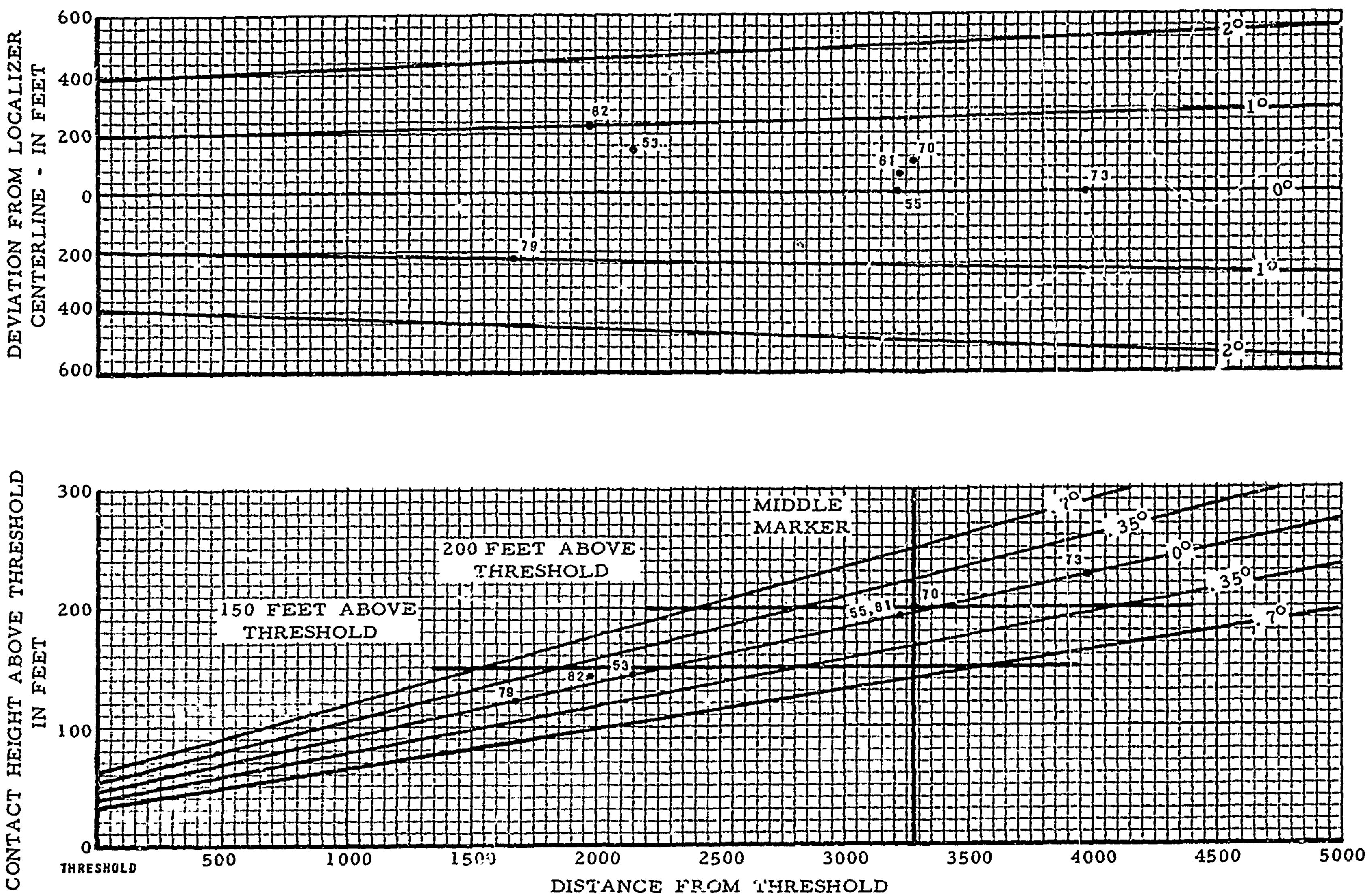


FIG. 10 ALCH AND ILS DEVIATION - PATTERN IV, NIGHT APPROACHES

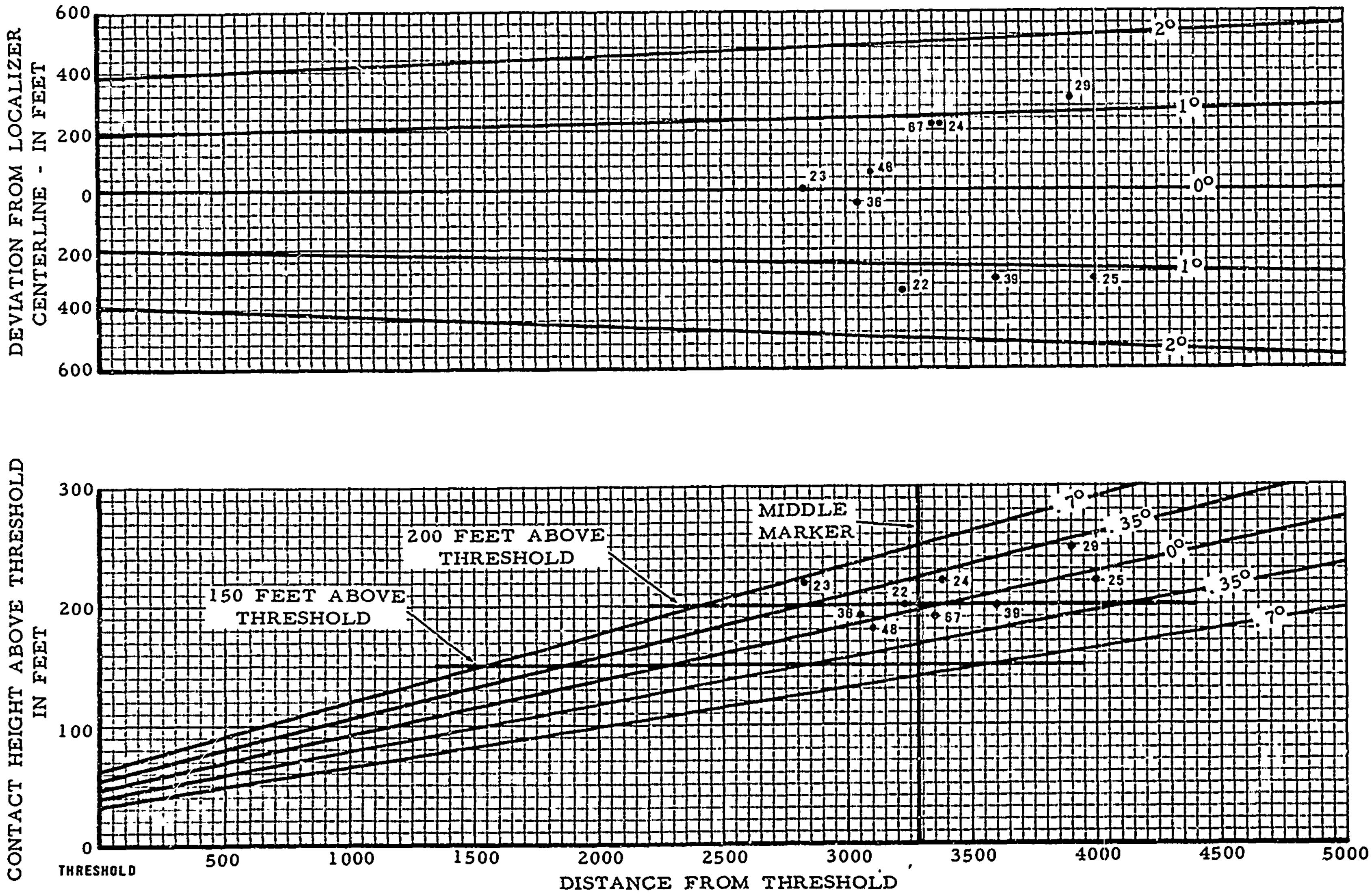


FIG. 11 ALCH AND ILS DEVIATION - PATTERN A, DAY APPROACHES

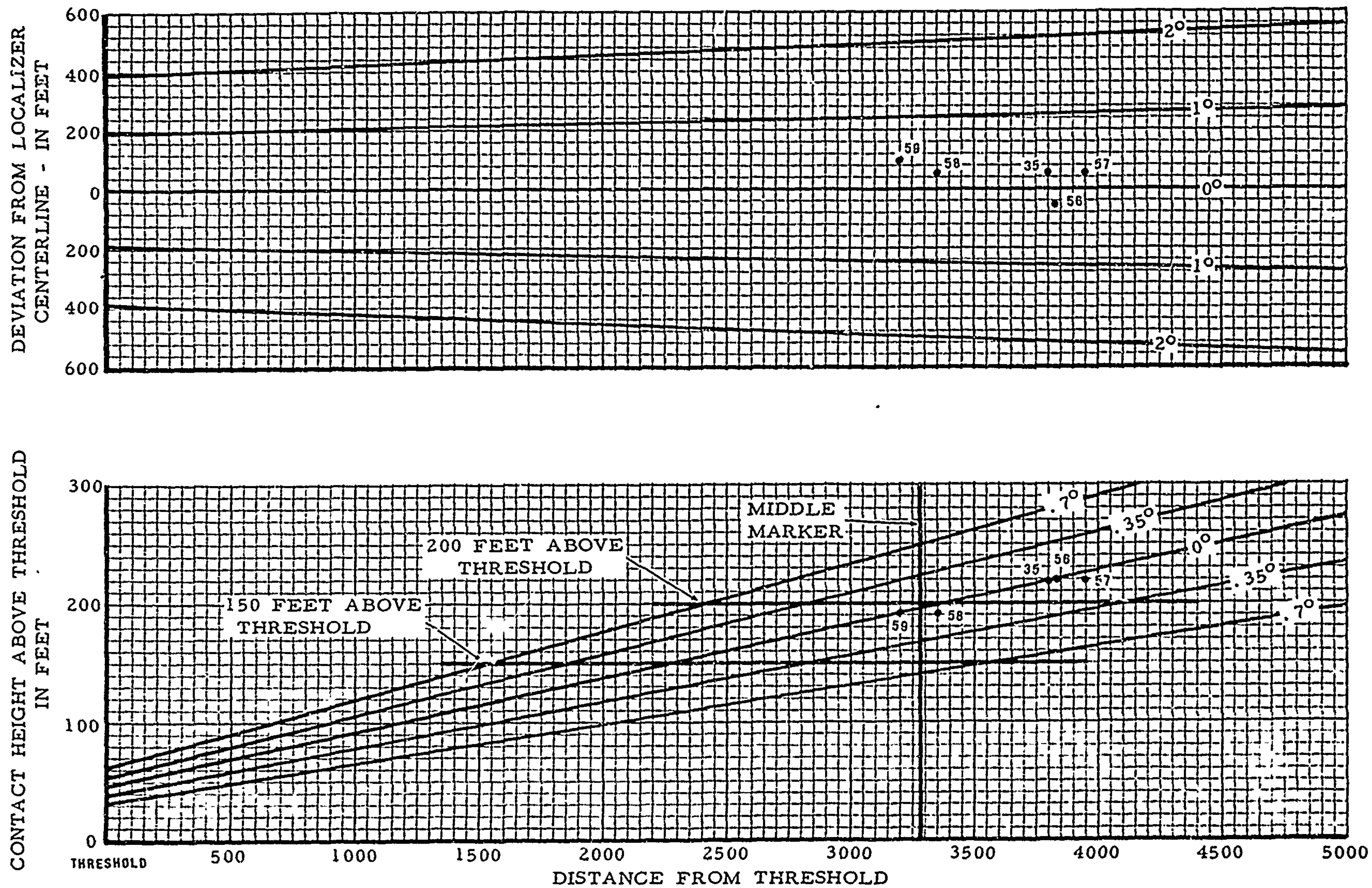


FIG. 12 ALCH AND ILS DEVIATION - PATTERN A, NIGHT APPROACHES

TABLE II

ALCH COMPARISON BY PATTERN
FOR BOTH PILOT AND MOTION PICTURE DATA

ALS Pattern	No. of Runs Included	Pilot Reports of ALCH Converted to Distance from Threshold and Averaged	Motion Picture Film ALCH Converted to Distance from Threshold and Averaged
I	9	2770 Ft.	2636 Ft.
III	7	2246 Ft.	2226 Ft.
IV	5	3082 Ft.	3129 Ft.
A	10	3424 Ft.	3791 Ft.

TABLE III

ALCH COMPARISON FOR PATTERNS I AND III
IN THE SAME WEATHER PERIOD

Run No.	ALCH	
	Pattern I	Pattern III
68	186 Ft.	
69		166 Ft.
71	156 Ft.	
72		166 Ft.
74	166 Ft.	
75		171 Ft.
77	214 Ft.	
78		224 Ft.
80	134 Ft.	
81		154 Ft.
83	144 Ft.	
84		134 Ft.

From Table IV, the average ALCH for the combination of Patterns I and III was 154 feet and the average ALCH for Pattern A was 196 feet. This shows that when a comparison with the shorter systems is made, an ALCH improvement of approximately 42 feet may be expected with the U. S. Standard system.

In a like manner, test results in similar weather conditions indicate the difference in performance between Pattern IV and Pattern A. Data shown in Table V are limited for this comparison, but they do reveal in one instance a higher ALCH for Pattern A. From Table V, the average ALCH for Pattern IV is 182 feet and the average for the Pattern A is 192 feet. Since data were available for only three pairs of approaches, a further comparison can be made between Pattern IV and the combination of Patterns I and III. These results are shown in Table VI.

From Table VI, the average ALCH for the combination of Patterns I and III is 150 feet and the average ALCH obtained for Pattern IV is 180 feet. This shows that when a comparison with the shorter Patterns I and III is made, an ALCH improvement of approximately 30 feet may be expected with Pattern IV.

Table VII summarizes the results of the several comparisons of patterns in the same weather periods.

Further data were obtained on system performance using motion picture film for all Pattern A runs. The photo-optical data analyzer was used to establish the difference in ALCH between Pattern A and Pattern III by determining the point in space where the first barrette became visible and the point in space where the barrette 1,500 feet (the beginning of Pattern III) from the runway threshold became visible. The difference between these two points for 10 approaches was converted to time which resulted in an average of 5.2 seconds. The rate of descent at 120 knots ground speed (5 knots below 125 knots for head wind) is 9.1 feet per second on the glide slope at NAFEC. For 5.2 seconds of time, 9.1 feet per second is 47.3 feet of altitude, the ALCH improvement of Pattern A over Pattern III.

4. Condenser-Discharge Lights: For nine daylight approaches, two pilots reported not seeing the condenser-discharge lights when asked, "Did you see the condenser-discharge lights; and if you saw them, did they assist in making the approach?"

TABLE IV

ALCH COMPARISON FOR PATTERNS I AND III (COMBINED) WITH PATTERN A IN THE SAME WEATHER PERIOD

Run No.	ALCH	
	Pattern I and Pattern III	Pattern A
21	173 Ft.	
22		193 Ft.
34	173 Ft.	
35		213 Ft.
38	153 Ft.	
39		193 Ft.
40	153 Ft.	
59		186 Ft.
60	116 Ft.	

TABLE V

ALCH COMPARISON FOR PATTERNS IV AND A IN THE SAME WEATHER PERIOD

Run No.	ALCH	
	Pattern IV	Pattern A
48		173 Ft.
49	173 Ft.	
55	186 Ft.	
56		216 Ft.
66	186 Ft.	
67		186 Ft.

TABLE VI

ALCH COMPARISON FOR
PATTERNS I AND III (COMBINED)
WITH PATTERN IV IN THE SAME WEATHER PERIOD

Run No.	ALCH	
	Pattern I and Pattern III	Pattern IV
53		136 Ft.
54	136 Ft.	
55		186 Ft.
60	116 Ft.	
61		186 Ft.
62	136 Ft.	
64		136 Ft.
65	136 Ft.	
66		186 Ft.
69	166 Ft.	
70		196 Ft.
71	156 Ft.	
72	166 Ft.	
73		221 Ft.
74	166 Ft.	
75	171 Ft.	
76		196 Ft.

TABLE VII

ALCH SUMMARY FOR PATTERN PERFORMANCE

Patterns Compared	Highest ALCH	ALCH Improvement
I with III	III	2 Ft.
Combination of I and III with IV	IV	30 Ft.
Combination of I and III with A	A	42 Ft.
IV with A	A	10 Ft.

TABLE VIII

EFFECT OF BACKGROUND BRIGHTNESS ON PATTERN PERFORMANCE

Run No.	Pattern	Localizer Displacement (Microamperes)	ALCH	Background Brightness (Foot-Lamberts)	Pilot Comment
64	IV	30	136	840	Did not see strobes - like to see more brightness
65	III	15	136	910	Much better guidance than previous pattern

Two pilots reported seeing the lights during a daylight operation; one pilot said they were of no help; and the other pilot said they helped but were not needed.

In reviewing the film, it was evident that the the condenser-discharge lights were not turned on (or had failed) for eight of the nine approaches when pilots had not seen the lights during daylight approaches. This reduced pilot opinion available for condenser-discharge lights to a few reports. However, absence of the lights did not result in inadequate ratings and this coupled with the comments of the two pilots who reported seeing the lights indicates that very little is gained during daylight hours by providing condenser-discharge lights in the system for the weather conditions flown.

The condenser-discharge lights were useful during the night in providing early visual guidance. One pilot remarked that the condenser-discharge lights were not needed once the steady-burning lights were in sight.

5. Effect of Background Brightness: One pilot reported much better guidance from Pattern III than from Pattern IV for the same weather conditions of W2X and 3,000 feet visual range. However, a higher background brightness level existed at this time than was encountered during most day runs. Table VIII shows the data for these two approaches.

   The difference in the patterns noted by the pilot indicates that the 100-foot spacing provides a boldness of signal that becomes more apparent in the higher background brightness of daylight.

6. Localizer Displacement: Motion picture film was relied upon as the primary data for an analysis of the effect of localizer displacement on runway alignment, but, unfortunately, considerable film was lost due to power problems and camera jamming. Of the total of 52 approaches available for data analysis purposes, 28 could be analyzed for the effect of localizer displacement using motion picture film. Table IX shows the distance from threshold where alignment of the aircraft with the runway was considered to be established after maneuvering (if required) from the localizer displacement and ALCH shown for the run. Alignment was considered to be established with the runway when the aircraft was tracking parallel or toward the runway centerline from a position that required little or no additional maneuvering to touchdown.

TABLE IX

EFFECT OF LOCALIZER DISPLACEMENT ON RUNWAY ALIGNMENT

Run No.	Pattern	ALCH	Localizer Displacement	Alignment Established with Runway (Distance from Threshold in Feet)
21	I	173 Ft.	.8R	-405
22	A	193 Ft.	.7L	At Threshold
23	A	213 Ft.	0	2840
24	A	213 Ft.	.5R	3221
25	A	213 Ft.	.6L	2937
29	A	243 Ft.	.6R	2026
31	I	143 Ft.	.6R	-2127
33	I	193 Ft.	.5L	1519
34	I	173 Ft.	.5L	1762
35	A	213 Ft.	.1L	3039
36	A	173 Ft.	.1L	2856
37	I	203 Ft.	.5L	2309
38	I	153 Ft.	.5R	-1215
39	A	193 Ft.	.6L	1924
40	I	153 Ft.	.5L	1357
41	I	173 Ft.	.3L	1114
42	III	133 Ft.	.5L	1053
43	III	133 Ft.	.6R	-911
44	III	133 Ft.	.6R	891
48	A	173 Ft.	.1R	2836
50	IV	203 Ft.	.5R	3241
64	IV	136 Ft.	.2R	2125
65	III	136 Ft.	.1R	2228
66	IV	186 Ft.	.5R	1904
67	A	186 Ft.	.5R	2147
73	IV	221 Ft.	0	3707
75	III	171 Ft.	.1R	2900
76	IV	196 Ft.	.1L	3400

The lack of data at 0.3 and 0.4 of full-scale deviation was due to the localizer bias device being either on or off throughout the test program.

The maximum bank angle noted by observers was 18 degrees. The 18-degree angle of bank was recorded three times during the program--twice for localizer displacements of 90 microamperes to the right and once for a 75 microampere to the left.

The moderate angles of bank experienced in the program for large localizer displacements confirm test results in previous programs indicating that pilots maneuver aircraft in actual weather conditions at quite conservative bank angles.

C. ANALYSIS OF TEST RESULTS:

1. Weather Measuring and Reporting: The measurement of cloud base at NAFEC and at many major airports in the United States, is made by use of a rotating beam ceilometer located at the middle marker site. The reportable value of sky-cover height is in even 100-foot increments. A measured value of 51 feet is reported as 100 feet as is a measured value of 150 feet. It can be seen that this procedure alone is one factor which limits the usefulness of ceiling reports in predicting whether a pilot will make contact with the approach lights at or above the minimum height approved for an approach.

   The rotating beam ceilometer provides a fairly reliable measure of ceiling height when there is good visibility underneath, but two problems are encountered when fog is present. The condenser-discharge lights in the ALS cause interference which makes it difficult to determine cloud height. A more serious problem concerns the effectiveness of the equipment when fog at the surface restricts forward visibility to approximately one-half mile and below. Then, the signal of the rotating beam ceilometer is broad from the surface upward and cannot be used to indicate either a cloud base height or vertical visibility. Consequently, the weather observer normally makes estimates of ceiling height based on known landmarks and issues reports of ceiling height in terms of vertical visibility into the fog. These reports are classified as indefinite obscurations; i.e., W2X. Such reports composed the majority of ceiling heights for this project and were found useful as only a general indication of the vertical visibility existing during an approach. In five instances, contact was made above a 200-foot height with a 100-foot ceiling report. Also in four instances, contact was made below a 200-foot height with a 300-foot ceiling report.

Horizontal visibility (runway visual range or visual range) reports alone gave little indication of what ALCH could be expected during an approach. There was only a slight trend toward higher ALCH as the visibility increased. This was due to the combined effect of low ceiling and fog below the clouds which prevented slant visibility from increasing in proportion to the increase in horizontal visibility. Similar effects have been observed at Arcata, California;[2] Newark, New Jersey;[3] and Atlantic City, New Jersey.[4]

The following statement, taken from the Final Report of the Newark, New Jersey, tests, applies to results obtained in this project:

> "Nevertheless, it is also apparent from all studies of this nature that ceiling and visibility values are grossly inadequate in describing approach visibility conditions, and most pilots have very little confidence in these reports."

In summary, major problems exist in weather measuring and reporting procedures for Category I and lower visibility operations. Aircraft are often delayed when weather is above authorized minimums and they are often cleared for approaches when the weather is below authorized minimums. It is apparent that improvement of meteorological services is needed to more accurately indicate the height at which a pilot can expect to make contact with the ALS when conducting an ILS approach.

2. Authorized Landing Minimums: Federal Air Regulations, Part 91.117 (h), states that no person may operate an aircraft below the applicable minimum altitude unless clear of clouds

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(2) Final Report, "Landing Aids Experiment Station," 1949.

(3) Final Report, "Approach Visibility Studies at Newark," FAA, AMB Project D-1-902, September 1960.

(4) Final Report, "Studies in the Field of Approach Visibility Measurement and Instrumentation," FAA, Project 202-2-1X, April 1962.

nor descend more than 50 feet below the minimum altitude unless certain other conditions are met. This rule, used for many years prior to minimums of 200-foot ceiling and 1/2-mile visibility being authorized for ILS approaches, has proven valid for instrument approaches at the higher minima. It seems apparent from the test results obtained in this project that a revision is needed for operating at the lower visibilities using ILS. The rule is given in its present form for reference purposes:

> 91.117 (h) Descent Below IFR Landing Minimums:
>
> "No person may operate an aircraft below the applicable minimum landing altitude unless clear of clouds. In addition, no person may operate an aircraft more than 50 feet below that minimum altitude unless: (1) The landing minimums are at least ceiling 1,000 feet and visibility two statute miles; or (2) the aircraft is in a position from which a normal approach can be made to the runway of intended landing and the approach threshold of that runway or the approach lights or other markings identifiable with that runway are clearly visible to the pilot. If, after descent below the minimum altitude the pilot cannot maintain visual reference to the ground or ground lights, he shall immediately execute the appropriate prescribed missed approach procedure."

When pilots made ILS approaches when indefinite ceilings were reported, determining when the aircraft was clear of clouds was, in a sense, foreign to the operation being conducted. Such an operation is often referred to as "operating in a homogeneous fog" (although fog is apparently never homogeneous) and does not involve breakout from a cloud base as the Federal Air Regulations, Part 91.117 (h), indicate.

A solution to the problem may be to adopt a new rule for operating on precision approach runways where minimum decision heights of 200 feet and lower are authorized while continuing to apply the present rule for instrument approach runways (VOR, ADF, etc., type approaches) and precision approach runways where minimums of 300 feet and higher are authorized. The new rule could be worded along the following lines:

"No person may operate an aircraft below authorized minimum decision heights of 200 feet or lower unless visual reference has been established with the ALS and the aircraft is in a position from which a normal approach can be made to the runway of intended landing. If after descent to the minimum decision height the pilot cannot maintain visual reference with the approach lights, he shall immediately execute the appropriate missed approach procedure."

Since there was a poor relationship between ceiling height as reported by the U. S. Weather Bureau and ALCH, it appears that minimum decision heights for ILS approaches should be based on factors such as obstructions, ground and airborne navigational equipment, altimeter accuracy, aircraft performance (altitude loss on go-around), and pilot proficiency. Weather minima should then be authorized (considering the state-of-the-art) which would provide the desired approach success rate at the established minimum decision height. The following analysis of test data and weather reports are made along these lines for minimum decision heights of 150 feet and 200 feet for Patterns I and III.

The average ALCH for Patterns I and III (combined) was 141 feet in W1X ceiling conditions. The 141-foot average ALCH indicates that a high missed approach rate would result by operating on short patterns with a minimum decision height as low as 150 feet in a W1X ceiling. It is apparent that, in the interest of safety and efficiency, U. S. Weather Bureau ceiling reports higher than 100 feet are required for a 150-foot minimum decision height.

An approach success rate of 83.4 percent would have been achieved for Patterns I and III (combined) with a minimum decision height of 150 feet when operating with ceiling reports as low as 200 feet (two possible missed approaches out of 12). The approach success rate would have dropped to 16.7 percent had there been an increase in the minimum decision height from 150 feet to 200 feet on Patterns I and III with ceiling reports as low as 200 feet (10 possible missed approaches out of 12). This analysis of approach success rates included only those approaches in reported ceiling heights of 200 and 300 feet and are Run Nos. 21, 31, 32, 33, 34, 40, 41, 65, 75, 77, 78, and 85, as shown in Appendix I.

Since data obtained in this project for reported ceilings of 300 feet were inadequate for analysis purposes, data provided in Reference 4, page 31, were used to supplement the ALCH analysis. That report shows, for 36 day-approaches with reported ceilings of 300 feet, an average ALCH of 254 feet was obtained for the U. S. Standard ALS. Applying the results obtained in this project of approximately 45 feet difference in ALCH between the shortened systems and Pattern A, it appears that for reported ceilings of 300 feet a minimum decision height of 200 feet would be required for Patterns I and III in order to achieve a satisfactory approach success rate. A further indication of this problem is shown by the missed approach for Run No. 32 that occurred on Pattern I in a W3X ceiling and 4,000-foot visual range weather condition, the only missed approach in the project when weather conditions met criteria. The pilot rated guidance as inadequate after seeing lights at an ALCH of 173 feet.

3. <u>Altimeter System Error and Approach Light Contact Height:</u> The altimeter system error of two Convair T-29 aircraft used in the project was determined prior to the flight test program by flying an ILS approach at the same speed and configuration as in the project and tracking the aircraft with phototheodolite equipment. An event switch, to mark the phototheodolite film, was actuated by the crew when the aircraft indicated 200 feet. The errors obtained for the aircraft systems were averaged over several runs and both aircraft were found to have a +94-foot system error.

This method of calibrating altimeter system error was correlated with a simpler procedure in good weather conditions whereby the pilot flew an ILS approach on glide path but displaced on the localizer course (about 0.3 of full-scale needle deflection). This permitted an observer in the cockpit to call out the exact instant that the aircraft passed abeam of the middle marker site. The crew noted the indicated altitude when advised by the observer. This method provided results very close to those obtained by phototheodolite tracking.

The Federal Air Regulations do not require a pilot to correct indicated altitude for altimeter system error when conducting an instrument approach; however, FAA Advisory Circular AC 120-15 dated October 2, 1964, contains the following requirement concerning the use of barometric altimeters for Category II operations:

Resolution of the Decision Height:

"If operation is predicated on the use of barometric altimeters, the decision height will be modified by the bias error determined to exist in the indicated pressure altitude; i.e., bias error 20 feet plus 100 feet equals 120-foot decision height."

In view of the rather large altimeter system errors existing in some aircraft (for example 94 feet for Convair T-29 aircraft at NAFEC), it is considered advisable to develop a similar rule for Category I operations. The method used in this project of flying accurately on glide path and noting altimeter reading at the middle marker appears suitable for determining the bias error for the altimeter system. Approach charts include the glide path height at the middle marker. A more accurate determination of bias error is obtained by subtracting the height of the aircraft glide slope antenna above the gear from the published glide path height at the middle marker. This was the method used in obtaining height data in this project.

4. The Effectiveness of Condenser-Discharge Lights: Pilot comments indicate that the condenser-discharge lights are considered to be extremely important for initial visual contact at night, but once the steady-burning lights become visible the pilots prefer to have them turned off. By day, the steady-burning lights are operated at intensities that provide approximately twice the effective intensity of the condenser-discharge lights. Pilots do not obtain the same relative effectiveness from the condenser-discharge lights by day as by night because at night, the effective intensity of the condenser-discharge lights is approximately 16 times that of the steady-burning lights. At night, the steady-burning lights are decreased in intensity to 4 percent of the daytime intensity to prevent glare, whereas the condenser-discharge lights always operate at a fixed intensity. Even so, the apparent motion and bluish-white color of the condenser-discharge lights cause them to be visible in daylight at about the same time as steady-burning lights when the aircraft is centered on the localizer course and about a second prior to the steady-burning lights when off to one side. The tests indicate that condenser-discharge lights should be provided (as tested at night) in the outer portion of the system up to and including the 1,000-foot bar, primarily for use at night.

5. Localizer Displacement: Data relative to maximum allowable localizer deviations for ALCH values were derived from approaches to Runway 13 at NAFEC, Atlantic City, New Jersey. The ILS serving this 10,000-foot runway has a nominal course width of four degrees, with the localizer antenna situated 11,000 feet from the runway threshold. ILS installations at smaller airports (shorter runways) will utilize a "tailored" localizer component, with the course width adjusted (to a limit of six degrees) to obtain a course width of 700 feet at the runway threshold. Mathematical analysis of the most extreme case of tailoring possible, that of a 5,750-foot runway with a six-degree course width localizer, shows that the course sector of the tailored localizer coincides very closely with that of the NAFEC localizer within the most critical segment of the approach path (3,000 feet from threshold to threshold) (see Figure 13). Application of the NAFEC test results to these tailored localizers on shorter runways will result in displacement variations of only a few feet inside or outside of those obtained during the NAFEC evaluation.

   Data contained in Table IX is limited for analysis of localizer displacement, but it appears evident that 0.6 of full-scale deviation resulted in alignment with the runway near and beyond runway threshold where ALCH was as low as 150 feet and lower. Displacements of 0.5 of full-scale deviation shows considerable improvement; but in one case, alignment was established after passing the runway threshold. From the data available, displacements of 0.4 of full-scale deviation at 150-foot height and displacements of 0.6 of full-scale deviation at 200-foot height would appear to provide a high probability of approach success.

D. SUMMARY OF TEST RESULTS:

1. Pattern A, the U. S. Standard ALS, and Pattern IV provided an average ALCH of approximately 190 feet which was approximately 45 feet higher than that obtained for Patterns I and III.

2. There was no substantial difference in the average ALCH obtained for Patterns I and III or for Patterns A and IV when flown in similar weather conditions.

3. The primary difference in patterns having the same or approximately the same length was due to the boldness of signal inherent in Patterns A and III because of the closer spacing (100 versus 200 feet) of the barrettes and was most noticeable in daylight high-background brightness conditions.

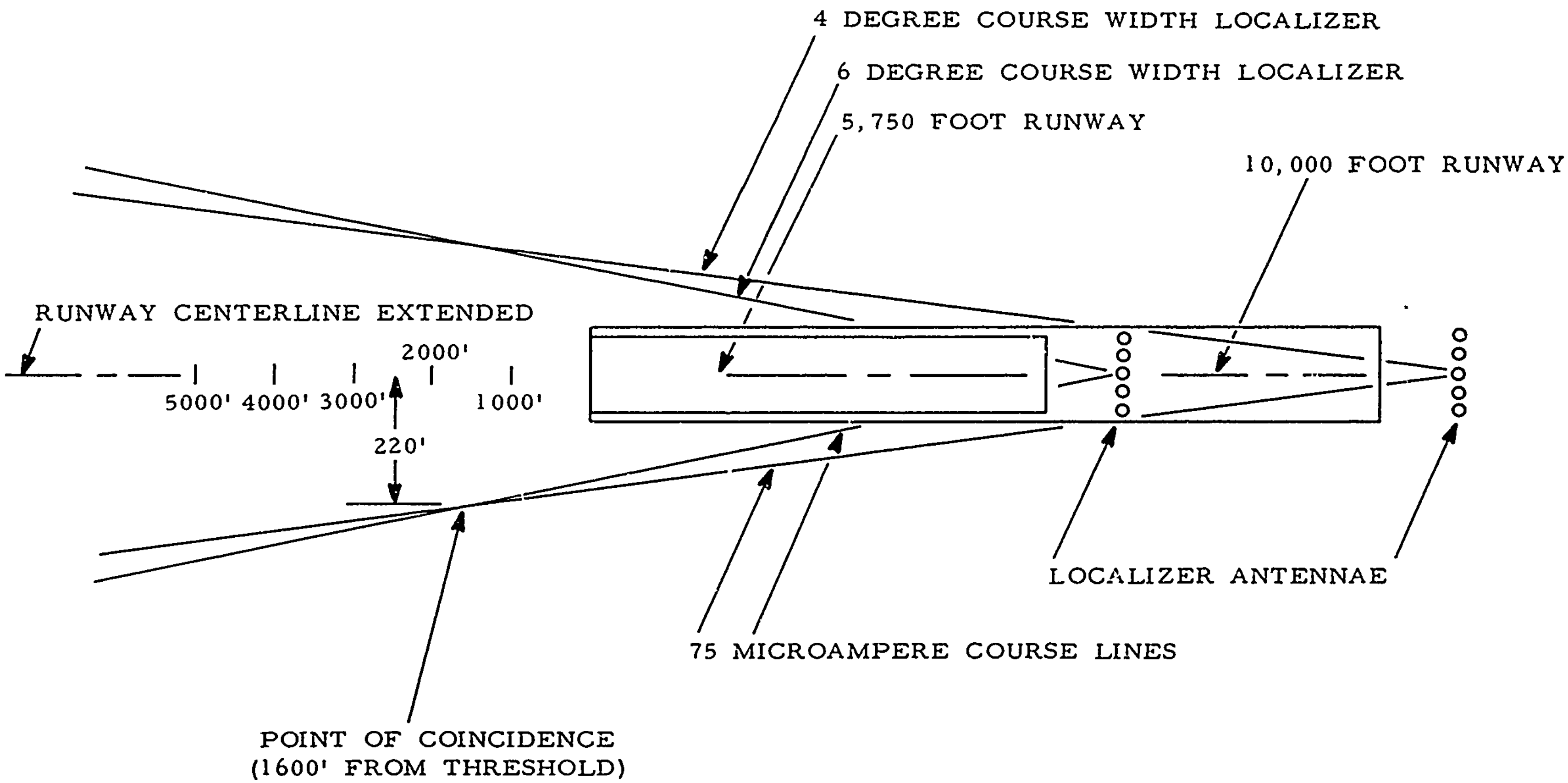

FIG. 13 COMPARISON OF FOUR-DEGREE AND SIX-DEGREE LOCALIZER COURSE WIDTHS

4. The condenser-discharge lights were effective in establishing ALCH at night. They were considered neither effective in establishing ALCH by day or necessary in flying the systems after visual reference was established with the steady-burning lights by day or by night.

5. Pattern I, the minimum system, provided adequate guidance after visual reference was established with the system. However, visual reference was normally established well below a 200-foot height above the runway in the weather conditions flown.

6. The use of visual range alone was of little value in predicting the ALCH for any approach light system flown.

7. ALCH was often established below a 200-foot height when the ceiling was reported as 200 feet and was always above a 100-foot height when the ceiling was reported as 100 feet in the weather conditions flown.

8. A bank angle of approximately 18 degrees was not exceeded in maneuvering toward the runway after ALCH was established.

9. Localizer displacement of 90 microamperes (0.6 full-scale) often resulted in alignment being established with the runway near or after the threshold when ALCH was below 150 feet. As the ALCH approached 200 feet, alignment with the runway was attained by a normal maneuver well ahead of the threshold with the 90 microampere localizer displacement.

CONCLUSIONS

Based upon the results of the evaluation of minimum approach light systems for lower activity airports described in this report, it is concluded that:

A. To realize a high probability of approach success rate using Patterns I or III, the following adjustments to operating practices are suggested for consideration:

1. Authorize a minimum decision height of 200 feet under reported 300-foot ceiling and 1/2-mile visibility weather conditions.

2. Authorize a minimum decision height of 150 feet under reported 200-foot ceiling and 1/2-mile visibility weather conditions provided that:

   a. Pilots demonstrate competency in conducting ILS approaches within 60 microamperes of the localizer course.

   b. The barometric altimeter system bias error is applied to indicated altitude to obtain true minimum decision height.

   c. Federal Air Regulation, Part 91.117(h) is revised to prohibit descent below the minimum decision height unless visual reference has been established with the approach light system and the aircraft is in a position from which a normal approach can be made to the runway of intended landing.

B. A high percentage of missed approaches at the lower limits of Category I (200-1/2) can be anticipated using Pattern I or Pattern III in today's operating environment except that aircraft having positive altimeter system errors will experience improved approach success rates (assuming good localizer and glide path alignment) in proportion to the magnitude of the altimeter system error.

C. Pattern I and Pattern III were essentially equivalent in approach success rate as were Pattern IV and Pattern A. Pattern III and Pattern A, having twice the number of centerline barrettes as

Pattern I and Pattern IV respectively, would show improved approach success rates in the higher background brightnesses not experienced in these trials.

D. Condenser-discharge lights should be provided at all stations of Pattern I or Pattern III in the outer portion of the systems up to and including the 1,000-foot bar.

E. A requirement exists to measure slant visibility to provide pilots with more accurate ALCH information.

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Mr. Kenneth Johnson
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APPENDIX I

DATA FOR 52 APPROACHES SELECTED FOR DATA ANALYSIS PURPOSES

Run No.	Condition	Pattern	ALCH	Guidance Adequate	Weather	Background Brightness
21	Day	I	173 Ft.	Yes	M2 4000 Ft. Visual Range	9 fL
22	Day	A	193 Ft.	Yes	M1 3800 Ft. Visual Range	17 fL
23	Day	A	213 Ft.	Yes	W2X 3500 Ft. Visual Range	31 fL
24	Day	A	213 Ft.	Yes	W1X 3000 Ft. Visual Range	50 fL
25	Day	A	213 Ft.	Yes	W1X 4000 Ft. Visual Range	80 fL
29	Day	A	243 Ft.	Yes	W2X 2000 Ft. Visual Range	600 fL
31	Night	I	143 Ft.	Yes	W3X 3600 Ft. Visual Range	------
32	Night	I	173 Ft.	No	W3X 4000 Ft. Visual Range	------
33	Night	I	193 Ft.	Yes	W3X 5000 Ft. Visual Range	------
34	Night	I	173 Ft.	Yes	W3X 5200 Ft. Visual Range	------
35	Night	A	213 Ft.	Yes	W1X 3300 Ft. Visual Range	------
36	Day	A	173 Ft.	Yes	W2X 3300 Ft. Visual Range	Not Taken
37	Day	I	203 Ft.	Yes	-X 4400 Ft. Visual Range	29 fL
38	Day	I	153 Ft.	Yes	-X 4600 Ft. Visual Range	50 fL
39	Day	A	193 Ft.	Yes	-XM3 4600 Ft. Visual Range	90 fL
40	Day	I	153 Ft.	Yes	W2X 4600 Ft. Visual Range	110 fL
41	Day	I	173 Ft.	Yes	W2X 4600 Ft. Visual Range	135 fL
42	Day	III	133 Ft.	Yes	W1X 3600 Ft. Visual Range	175 fL
43	Day	III	133 Ft.	No	W1X 3000 Ft. Visual Range	280 fL
44	Day	III	133 Ft.	Yes	W1X 3000 Ft. Visual Range	340 fL
48	Day	A	173 Ft.	Yes	-X 3800 Ft. Visual Range	720 fL
50	Day	IV	203 Ft.	Yes	-X 5200 Ft. Visual Range	2500 fL

(Continued)

APPENDIX I (Continued)

Run No.	Condition	Pattern	ALCH	Guidance Adequate	Weather	Background Brightness
53	Night	IV	136 Ft.	Yes	W1X 2800 Ft. Visual Range	------
54	Night	I	136 Ft.	Yes	W1X 2600 Ft. Visual Range	------
55	Night	IV	186 Ft.	Yes	W1X 2200 Ft. Visual Range	------
56	Night	A	216 Ft.	Yes	W1X 1600 Ft. Visual Range	------
57	Night	A	216 Ft.	Yes	W1X 1800 Ft. Visual Range	------
58	Night	A	186 Ft.	Yes	W1X 2000 Ft. Visual Range	------
59	Night	A	186 Ft.	Yes	W1X 2600 Ft. Visual Range	------
60	Night	III	116 Ft.	Yes	W1X 2600 Ft. Visual Range	------
61	Night	IV	186 Ft.	Yes	W1X 2800 Ft. Visual Range	------
62	Night	III	136 Ft.	Yes	W1X 3000 Ft. Visual Range	------
64	Day	IV	136 Ft.	Yes	W2X 3000 Ft. Visual Range	840 fL
65	Day	III	136 Ft.	Yes	W2X 3000 Ft. Visual Range	910 fL
66	Day	IV	186 Ft.	Yes	W2X 5000 Ft. Visual Range	710 fL
67	Day	A	186 Ft.	Yes	W2X 5000 Ft. Visual Range	Not Taken
68	Night	I	186 Ft.	No	W0X 2600 Ft. Visual Range	------
69	Night	III	166 Ft.	No	W0X 2600 Ft. Visual Range	------
70	Night	IV	196 Ft.	No	W0X 2800 Ft. Visual Range	------
71	Night	I	156 Ft.	Yes	W0X 3000 Ft. Visual Range	------
72	Night	III	166 Ft.	Yes	W1X 2800 Ft. Visual Range	------
73	Night	IV	221 Ft.	Yes	W1X 5000 Ft. Visual Range	------
74	Night	I	166 Ft.	Yes	W1X 5000 Ft. Visual Range	------
75	Day	III	171 Ft.	Yes	M3 5000 Ft. Visual Range	100 fL
76	Day	IV	196 Ft.	Yes	M3 5000 Ft. Visual Range	140 fL
77	Night	I	214 Ft.	Yes	M2 5000 Ft. Visual Range	------
78	Night	III	224 Ft.	Yes	M2 4600 Ft. Visual Range	------
79	Night	IV	114 Ft.	Yes	M1 3400 Ft. Visual Range	------

(Continued)

APPENDIX I (Continued)

Run No.	Condition	Pattern	ALCH	Guidance Adequate	Weather	Background Brightness
81	Night	III	154 Ft.	Yes	W1X 3200 Ft. Visual Range	------
82	Night	IV	134 Ft.	Yes	W1X 2500 Ft. Visual Range	------
83	Night	I	144 Ft.	Yes	W1X 3000 Ft. Visual Range	------
85	Night	III	154 Ft.	Yes	W2X 5000 Ft. Visual Range	------